MOCHA - Multi-Study Ocean Acoustics Human Effects Analysis

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LONG-TERM GOALS

The long-term goal is to substantially enhance our quantitative understanding of the response of marine mammals to navy sonar and other acoustic stimuli, by maximizing the information gain from Behavioural Response Studies (BRSs). We aim to develop and implement innovative methods for the analysis of BRS data, and to complement and enhance analyses already taking place as part of each current Navy-funded BRS project. We aim for synergies by looking at the studies in combination.

OBJECTIVES

The overall objective of this project is to develop and implement innovative statistical methodologies for the analysis of behavioral response study data. Our focus is on studies estimating the response to mid-frequency active sonar, but the methods developed will be widely applicable. We aim to maximize the inferences that can be drawn from current and ongoing studies as well as to provide advice on future studies. Advances will be made in close collaboration with those involved in existing BRS projects, using a working group format. This approach enables us to complement and enhance the analytical work already being undertaken, as well as to be flexible and incorporate new ideas as they arise in working group sessions.

The project has four specific objectives:

1. Improve methods for combining diverse behavioral measures into metrics of behavioral response. Consideration will be given to obtaining metrics that can be linked to biological consequences.
2. Improve methods for estimating dose-response functions for individual studies. This involves both developing and applying cutting-edge statistical methods, as well as considering which contextual variables in addition to acoustic dose can be incorporated into the analysis. The output will be improved estimates of response curves (with uncertainty) for each study.
3. Combine information across studies and species ("meta-analysis"), making use of expert biological opinion, to make predictions about taxa and contexts not yet studied. Differences in methods/protocols between studies will need to be accounted for.

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4. Based on the above, determine where major uncertainties still lie (through sensitivity analyses), and hence suggest where future experimental effort might be applied most fruitfully.

APPROACH

We have formed a working group, supported by two full-time post-doctoral researchers, to develop and implement innovative methods for the analysis of the results from BRSs. The working group is composed of the chief scientists of existing BRS projects (Sirena sonar trials on sperm whales, Bahamas BRS, SOCAL BRS, Norwegian 3S and 3S2, Cape Hatteras EK60 experiments and Cape Hatteras and Hawaiian BRS), together with other scientists working on BRS issues and statisticians who have expertise in the analysis of biological data of this kind. A smaller steering committee, comprising the PIs on this project and the BRS PIs, is providing overall direction.

Over the course of the project we are holding a series of workshops attended by the working group, steering group and project post-doctoral researchers. Each workshop is focusing on a functional/taxonomic group of marine mammals (deep divers, other odontocetes, pilot whales and baleen whales). We began with deep divers (beaked whales and sperm whales) because this group contains species of concern, there are data for these species across multiple BRS projects, the metrics measured are fairly well defined, and the social complexities are minimized. We then increased social complexity by looking at other odontocetes (killer whales, Risso's dolphins, false killer whale, melon-headed whale) and are now beginning to focus on pilot whales for which there are data from most BRSs. The 4th workshop will focus on baleen whales.

Two post-doctoral researchers (Stacy DeRuiter and Dina Sadykova) are conducting the majority of the research and model development over the course of the project under the supervision of Harris and Thomas, with frequent inputs from other project partners as required.

In the periods between workshops, small sub-sets of the working group are participating in technical groups to advance particular aspects of the project in parallel with the main effort. This format of separating conference call meetings into small technical meetings and larger progress meetings has worked very well within other projects coordinated by the PIs (such as the NOPP-facilitated DECAF project and the ONR-funded LATTE project).

WORK COMPLETED

The 3rd and 4th working group meetings have taken place within the last fiscal year, with the 3rd being hosted by TNO in the Netherlands in March 2013 and the 4th being hosted by Duke Marine Lab in September 2013. These workshops have focussed on other odontocetes (as defined above) and pilot whales respectively. The reports of these working group meetings can be found at http://www.creem.st-and.ac.uk/mocha/project-outputs. These species groups have provided an opportunity to look at more complex social behaviour and incorporate a wider range of variables into the analysis.

Alongside initiation of work on these species we have continued our method development for deep divers, the focus of our 2nd working group meeting. We have completed six working documents outlining analysis methods pertaining to beaked whale and sperm whale data. In addition, we have published the output from one deep-diver analysis led by MOCHA in a peer-reviewed journal

(DeRuiter et al. 2013 and see results below). Four of the six working documents describe methods for detecting change-points in an individual's behaviour over time in the presence of sound exposure. We are now carrying out a formal comparison of different change-point methods. We have also developed a Bayesian hierarchical framework for producing exposure-response relationships and have been working on the application of this framework to multiple species in one analysis.

We have also made progress in the application of process-based time series models such as hidden Markov models (HMMs) and semi-Markov models (SMMs) to BRS data. These models allow multiple metrics to be combined into one analysis, but they also explicitly acknowledge the time-series nature of the data, and provide an opportunity to explore behavioral states and the probability of transitioning between these states as a function of sound exposure.

As well as leading on some research avenues, we have also provided support to the individual BRS projects when requested. This has led to a number of collaborative publications (see publication list).

RESULTS

We have trialled Mahalanobis distance (Md) as a method for identifying change-points in time-series of DTAG data and have found it to be effective, both for change-point identification and also as a measure of response intensity (as demonstrated by DeRuiter et al., 2013). Md was derived from DTAG data from two *Ziphius cavirostris* tagged by the SOCAL project and peaks in Md were noted at the time of the controlled exposure events (Figure 1).

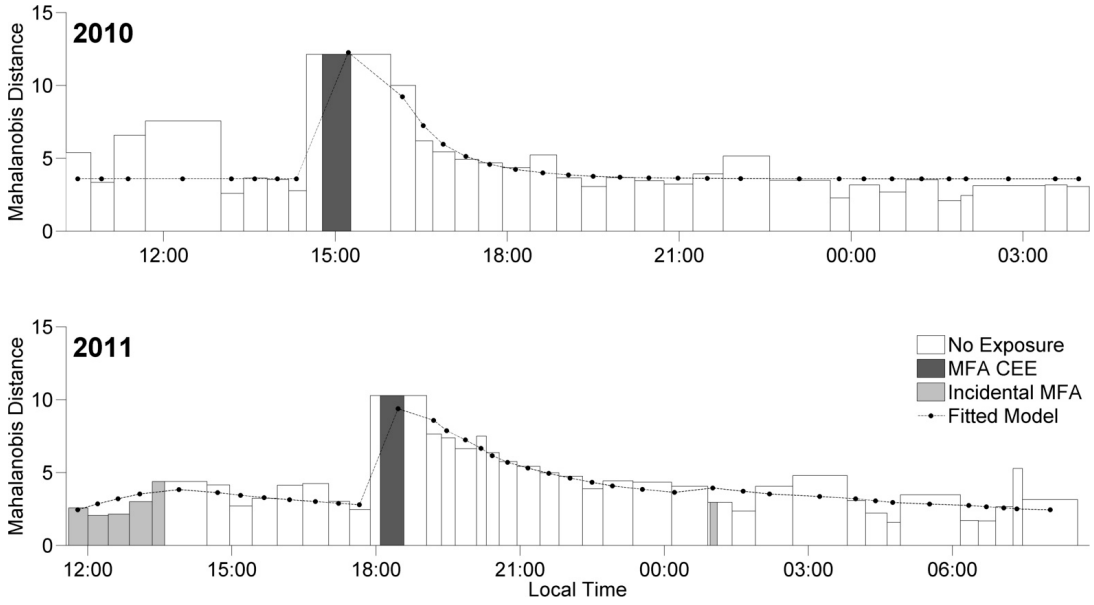

Figure 1: Mahalanobis distance (a proxy for response intensity) for each dive in the DTAG time-series for the Ziphius cavirostris tagged in 2010 and 2011. Each box relates to one dive cycle and the area shaded in dark grey is the period of controlled exposure and the area shaded in light grey is the incidental exposure in 2011. The dotted line relates to the fitted model. Figure adapted from DeRuiter et al. 2013.

As the 2011 whale was also exposed incidentally to MFA sonar from a distant naval exercise it was possible to model response intensity as a function of received level (RL), range and time since start of exposure. It was found that both RL and range affected the intensity of the response: similar RL from sources at different ranges resulted in different behavioural changes. This result highlights the importance of understanding the context of sound exposure and raises interesting experimental design questions about how to disentangle these two confounding variables.

IMPACT/APPLICATIONS

This project aims to significantly enhance the Controlled Exposure Experiments component of the Marine Mammals and Biology Program, and it will also address broader commitments of the Navy for environmental compliance. As part of rule making under the US Marine Mammal Protection Act, the Navy has committed to an Integrated Comprehensive Monitoring Program with the following objectives: monitor and assess the effects of Navy activities on protected marine species; ensure that data collected at multiple locations is collected in a manner that allows comparison between and among different geographic locations; assess the efficacy and practicality of the monitoring and mitigation techniques; add to the overall knowledge base of protected marine species and the effects of Navy activities on these species (Stone 2009). As part of its environmental compliance, the Navy must attempt to quantify the effect of sonar operations on marine mammals in all of its operating areas. This requires methods to estimate the relationship between acoustic dosage and other factors with behavioral responses. Here we propose to develop a framework to pool data across studies and areas to develop more systematic models to quantify these effects.

RELATED PROJECTS

Data to be analysed in the MOCHA project comes from a number of BRS projects that have focussed on different geographic areas and species. Below is a list of the projects providing data and links to websites with further information on each project, where available. More information about each project can be found in links listed at http://www.creem.st-and.ac.uk/mocha/links

- Sirena sonar trials on sperm whales
- BRS Bahamas (AUTEC): http://www.nmfs.noaa.gov/pr/acoustics/behavior.htm
- SOCAL BRS: http://sea-inc.net/socal-brs/
- 3S: http://soi.st-andrews.ac.uk/documents/424.pdf
- 3S2: http://www.ffi.no/no/Rapporter/11-01289.pdf
- Cape Hatteras: http://www.serdp.org/Program-Areas/Resource-Conservation-and-Climate-Change/Natural-Resources/Living-Marine-Resources-Ecology-and-Management/RC-2154/RC-2154

Other related research projects are:

- LATTE - This three year project is developing and implementing statistical models that integrate passive acoustic monitoring data and animal-borne tag data to estimate the effect of Mid Frequency Active (MFA) sonar on beaked whales at AUTEC.
- M3R program – This is the passive acoustics monitoring algorithms and tools development program at NUWC that has facilitated much of the data processing work used in the current project.

- PCADs – This project aims to operationalize the Population Consequences of Acoustic Disturbance framework, focusing (currently) on four case study species, including beaked whales at AUTEC.

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PUBLICATIONS

1st MOCHA Working Group Meeting Report, 2012. (Technical Report) Available at http://www.creem.st-and.ac.uk/mocha/project-outputs

2nd MOCHA Working Group Meeting Report, 2012. (Technical Report) Available at http://www.creem.st-and.ac.uk/mocha/project-outputs

3rd MOCHA Working Group Meeting Report, 2013. (Technical Report) Available at http://www.creem.st-and.ac.uk/mocha/project-outputs

4th MOCHA Working Group Meeting Report, 2013. (Technical Report) Available at http://www.creem.st-and.ac.uk/mocha/project-outputs

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